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THE RELATIVE RIGIDITY  
OF MONOPOLY PRICING

By  
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WP#1777-86

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## I. INTRODUCTION

The relationship between industry structure and pricing is a major focus of Industrial Organization. One of the most striking facts to have emerged about this relationship is that monopolists tend to change their prices less frequently than tight oligopolies. Although the first evidence in this regard was presented by Stigler (1947) almost forty years ago, no theoretical explanations have been offered. The objective of this paper is to develop models capable of explaining these facts.

Stigler's objective in comparing the relative rigidity of monopoly and duopoly prices was to test the kinked demand curve theory of Hall and Hitch (1939) and Sweezy (1939). Since the work of Gardiner Means (1935) seemed to show that concentrated industries exhibited greater price rigidity than their unconcentrated counterparts, the kinked demand curve was developed and embraced as providing a theoretical foundation for the rigidity of prices. It was widely regarded to be an implication of that theory that duopolists would not change their prices in response to small changes in their costs.<sup>1</sup>

Stigler's test was a direct and simple test of the rigidity of oligopoly prices. Instead of comparing oligopoly pricing with pricing in unconcentrated industries he simply compared the relative rigidity of monopoly and oligopoly prices. If it is the kink that leads to inflexible oligopoly prices, monopolists should have more flexible prices since monopolists do not face a kinked demand curve. Stigler found instead that monopolist's prices were even more rigid. Several later empirical studies

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<sup>1</sup>This view was emphasized by Bronfenbrenner (1940), for example. It is now well-recognized, however, that the kinked demand curve implies multiple equilibria. When cost conditions change one might well expect the equilibrium to change as well. It is only if the current price is somehow "focal" that the price will not change.

have supported his original finding: monopolist's change their prices less frequently than do oligopolists.

In his study, Stigler tabulated the number of price changes for two monopolistically supplied commodities (aluminum and nickel) and 19 products which were each supplied by a small number of firms. The source of the data on price changes was the Bureau of Labor Statistics bulletins, Wholesale Prices for the period June 1929 - May 1937. The price of nickel did not change at all over this period and there were only two price changes for aluminum. Among the oligopolistically supplied products, however, only one had fewer than four price changes (sulphur) and half had more than ten price changes.

The finding has been replicated on other price data for different periods. Simon (1969) studied advertising rates of business magazines from 1955 to 1964. Simon's data has the advantage that it contains the price series for each publication rather than simply an index of the industry price, as is the case for the BLS data. Simon finds that the average number of years in which an individual firm's price changes is monotonically increasing in the number of competitors it has.

Primeaux and Bomball (1974) compare pricing of electric power when it is supplied by a duopoly versus a monopoly. Their data cover 17 duopolies and 22 monopolies from 1959 to 1970. One advantage of their study is that there is no product differentiation in electric power so that there is no danger of misspecifying the firms' competitors. Also, list prices are transactions prices since deviations from printed schedules are illegal for public utilities. Their results show that when there are two firms in the market they each change their prices more often than a corresponding monopolist.

This is true for all levels of power usage. The effect is more pronounced for lower levels of power usage where the duopolists changed their prices two or three times more frequently than it is for higher power usages where they change their prices roughly one-and-a-half times as often.

Finally, Primeaux and Smith (1976) study the pricing of 88 major drugs during the period 1963-1973. For their sample they are unable to reject the hypothesis that a monopolist changes its price as frequently as each individual oligopolist. For the most part the monopoly prices they report are those for drugs about to go off patent. If monopolists have a tendency to change their prices in anticipation of the competition that is likely to ensue when the patent runs out, this might explain why the results here are weaker than in the cases reported above.

There thus seems to be a general tendency for monopolists to change their prices less frequently than oligopolists. The explanation that we offer for this phenomenon is based on the relative incentives of monopolists and oligopolists to adjust their prices when underlying cost and/or demand conditions change or when inflation erodes existing prices. We focus on the comparison between duopoly and monopoly and show that whether the products of the duopoly are homogeneous or differentiated, the duopolists have a greater incentive to change their prices than does a monopolist facing the same configuration of demand. So, if there are other forces leading to price rigidity that are of roughly comparable magnitudes across industry structures, there will be a general tendency for duopoly prices to change more frequently. There are a variety of reasons why prices may be unresponsive to changes in underlying conditions. We focus on two. The first reason is that there may be a fixed cost of changing prices. This idea was first put forward by Barro (1972) and has been used by Sheshinski and

Weiss (1979, 1985), Rotemberg (1982), and Mankiw (1985) among others. These costs are usually taken to include the physical costs of changing and disseminating price lists and the possibility of upsetting customers with frequent price changes. In the electric utility industry they also capture the costs of obtaining permission from regulatory authorities for changing tariffs. The second reason is that while firms may be aware that underlying conditions have changed, it may be costly for them to ascertain precisely how they have changed. For example, on the demand side, market research may be required to discover true demand, sales data may need to be analysed, or salepeople's opinions canvassed and aggregated. On the cost side, labor and material costs may have to be reestimated. At least when it is believed that only moderate changes in conditions have occurred, firms may then prefer not to change their prices to incurring these costs. Of course, absent a fixed cost to changing prices as well, this would only explain the reluctance of firms to change prices when their best estimate of the optimal price given the information they have is the current price itself.

Given the general reluctance of firms to change their prices, the question then is how the gains to the firms of changing their prices compare with the costs, and more importantly, how the gains differ across market structures. To see why duopolists in general have a greater incentive to change prices, consider the following simple case. Suppose that two firms competing in Bertrand style and charging price equal to constant marginal cost unexpectedly discover that costs have increased. If neither firm increases its price, the firms share the loss of supplying the entire market demand at a price below costs. The firms obviously have a large incentive to change their prices. Furthermore, if either firm believes its rival will change its price then it has an even greater incentive to raise its own price

in order to avoid suffering the entire loss itself. Put differently, when a firm changes its own price it imposes a negative externality on its rival: it increases the amount that the firm must sell at the "wrong" price.

A similar phenomenon arises for cost decreases. In that case there is no incentive for the firms to make a combined price decrease. However there are substantial incentives for either firm to make a unilateral price decrease to undercut the rival. Here again there is an externality: the deviating firm's gain is made at the rival's expense.

A monopolist's profits are differentiable in its price. Therefore, as Akerlof and Yellen (1985) show, the loss in profits from not changing its price is second order. Since the duopolist's incentives to change price are first order, if they face comparable costs of changing prices, the duopolists would change price more frequently than a monopolist would.

When oligopolists produce differentiated products individual firm's profits are again differentiable in their own prices and the Akerlof-Yellen argument still applies. One might believe, therefore, that the result that monopolists change their prices less frequently than duopolists would not hold in this case. We show that it does. The reason has to do with the externalities discussed above.

Consider duopolists producing differentiated products and, as above, suppose that costs increase slightly. Now if one firm raises its price slightly it no longer yields all of its customers to its rival. Profits are no longer discontinuous at the point of equal prices. However, it does lose some of its customers to its rival, and if the degree of substitutability is high it loses them at a rapid rate. In other words, the externality that the duopolist inflicts on its rival is increasing in the degree of substitutability between the products. Thus although the increase in profits from adjusting its price is second order, it may be large. A monopolist,

on the other hand, is able to internalise these externalities. For purposes of comparison, suppose that the monopolist offers both products. Now when it changes the price of either one it bears the full consequences: both the change in profits of the product whose price is changed and that of the product whose price is unchanged. Whereas the duopolists each have an incentive to change prices in order to make a gain at the other's expense, the monopolist has no such incentive.

Thus in the presence of fixed costs of changing prices the monopolist may adjust prices more sluggishly. In order to compare the relative frequency of price adjustments, it is important not to stack the deck against the monopolist by having it incur a fixed cost for changing each of its prices. Rather, to bias the conclusion away from our result we suppose that the monopolist can change both of its prices for what it costs each of the duopolists to do so. Even then we find that provided the cross-elasticity of substitution is high enough, the duopolists change their prices more frequently.

Similar motives tend to make duopolists more keen to discover changes in underlying conditions when discovery is costly. For example, if one firm discovers that costs have fallen it is able to exploit that information at the expense of its rival by lowering its price and attracting its rival's customers. Alternatively if it discovers that costs have increased it is able to increase its price and the rival suffers from having a large demand at an unremunerative price. These incentives do not apply to monopolists: they can therefore afford to be "lazy" in their collection of information.

We begin by examining the case of a fixed cost to changing prices. In Section II we develop intuition via a homogeneous goods example. This model is generalized to differentiated products and an inflationary environment in

Section III. In section IV we study the case where it is costly to discover the exact magnitude of a change in costs. We conclude with Section V.

## II. A Model with Homogeneous Products and Fixed Costs of Changing Prices

In order to demonstrate how the incentives for a monopoly to change prices differ from those of a duopoly we begin with a very simple model. In particular, we will assume that the duopolists produce a homogenous good with constant marginal costs and compete in prices a la Bertrand. As we shall see below, this formulation is useful for expository purposes since the incentives for changing prices are most apparent when the model is stripped down in this way.

Unfortunately, we will also see that this formulation is too stark in the sense that duopolists earn zero profits given of any fixed costs. Thus, they must bear any such costs, their participation becomes unprofitable. However, any number of modifications in the direction of realism (such as differentiated products or increasing marginal costs) would provide the firms with sufficient profits to cover small fixed costs. We begin with the simplest model and later show how product differentiation guarantees the willingness of the firms to participate.

Time is divided into two "periods" by an unexpected increase in the firms' constant marginal costs of production from  $c_1$  to  $c_2$ . We will refer to the periods before and after the cost change as periods 1 and 2 respectively. Inverse demand is given by  $P=a-bQ$ ,  $a>c_2$ . Since the duopolists compete in Bertrand style  $P_1^1 = P_1^2 = c_1$  (subscripts denote firms and the firm is indexed by the superscript). The monopolists, on the other hand, changes  $P_1^M = (a+c_1)/2$  and sells  $(a-c_1)/2b$ .

We explore how the change in costs affects prices. We consider what happens when the new level of marginal costs,  $c_2$ , is known to both firms before they select their period two prices, but where each firm must incur a fixed cost,  $f$ , to change its price.

If the monopolist leaves its price unchanged at  $P^M$  it sells  $(a-c_1)/2b$  and earns  $(\frac{a+c_1}{2} - c_2)(\frac{a-c_1}{2b})$ . If, on the other hand, it changes its price, it earns  $(a-c_2)^2/4b - f$ . It is therefore worthwhile to change price if and only if

$$\frac{(c_2 - c_1)^2}{4b} > f. \quad (1)$$

Now consider a duopolist. The amount demanded at  $P=c_1$  is  $q_1 \equiv (a-c_1)/b$ . Suppose that firm 2 does not change its price. If firm 1 doesn't change its price either the firms snare the loss of  $q_1(c_2 - c_1)$  i.e. they each lose  $(a-c_1)(c_2 - c_1)/2b$ . What happens if firm 1 increases its price? To do so it must incur the cost,  $f$ , and then it goes out of business. Thus firm 1 loses  $f$  if it raises its own price and firm 2 keeps its price unchanged. So firm 1 prefers to change its price if

$$(a-c_2)(c_2 - c_1)/2b > f. \quad (2)$$

Now consider what happens if firm 2 increases its price to  $c_2$ . Now firm 1 loses  $(a-c_2)(c_2 - c_1)/b$  if it maintains its period one price (since it now bears the entire loss itself). On the other hand it loses only  $f$ , if it joins firm 2 in the price increase to  $c_2$ . Thus it prefers to raise its price if

$$(a-c_2)(c_2 - c_1)/b > f \quad (3)$$

Equation (2) implies equation (3). Thus if (2) holds, changing price is

a dominant strategy and the unique equilibrium involves both firms changing price. If (3) holds but (2) does not, each firm is willing to change its price only if the other also does. There are then two equilibria: one in which the firms both change their prices and one in which neither does. Finally, if (3) does not hold then the unique equilibrium is that neither firm changes its price.

Now compare the relative incentives for the duopoly and the monopoly to change prices. To make the comparison unfavorable to frequent price changes by the duopoly, we concentrate on the case in which changing price is the unique equilibrium. Then the duopoly changes prices if (2) holds while the monopoly changes prices if (1) holds. Since  $a > (c_1 + c_2)/2$  by assumption, if (1) holds then (2) holds as well. Thus the duopolists would always change the price if the monopolist would. Moreover, if  $(a - c_2) > 2bf/(c_2 - c_1) > (c_2 - c_1)/2$  then (2) holds but (1) does not so that, for parameters in this range, the duopolists would change their prices whereas the monopolist would not.

The intuition for these results is clear from Figure 1 which illustrates the effect of a cost increase. The profit for a monopolist who sets the optimal price for costs  $c_2$  is given by the integral of marginal revenue minus marginal costs evaluated at  $q_2^M$  which equals the shaded area in Figure 1. If the monopolist doesn't change its price (so that it sells  $q_1^M$ ), it earns the profits it would earn if its costs were actually  $c_1$  (the area  $ac_1 z$ ) minus  $(c_2 - c_1) q_1^M = c_1 c_2 xyz$ . The loss from not changing its price is therefore the crosshatched triangle  $xyz = 1/2(c_2 - c_1)(q_1^M - q_2^M) = 1/2(c_2 - c_1)(\frac{a-c_1}{2b} - \frac{a-c_1}{2b}) = (c_2 - c_1)^2/4b$ . The monopolist is willing to change its price if this area exceeds  $f$ .

Now consider the duopolists. If firm 1 believes that firm 2 will not

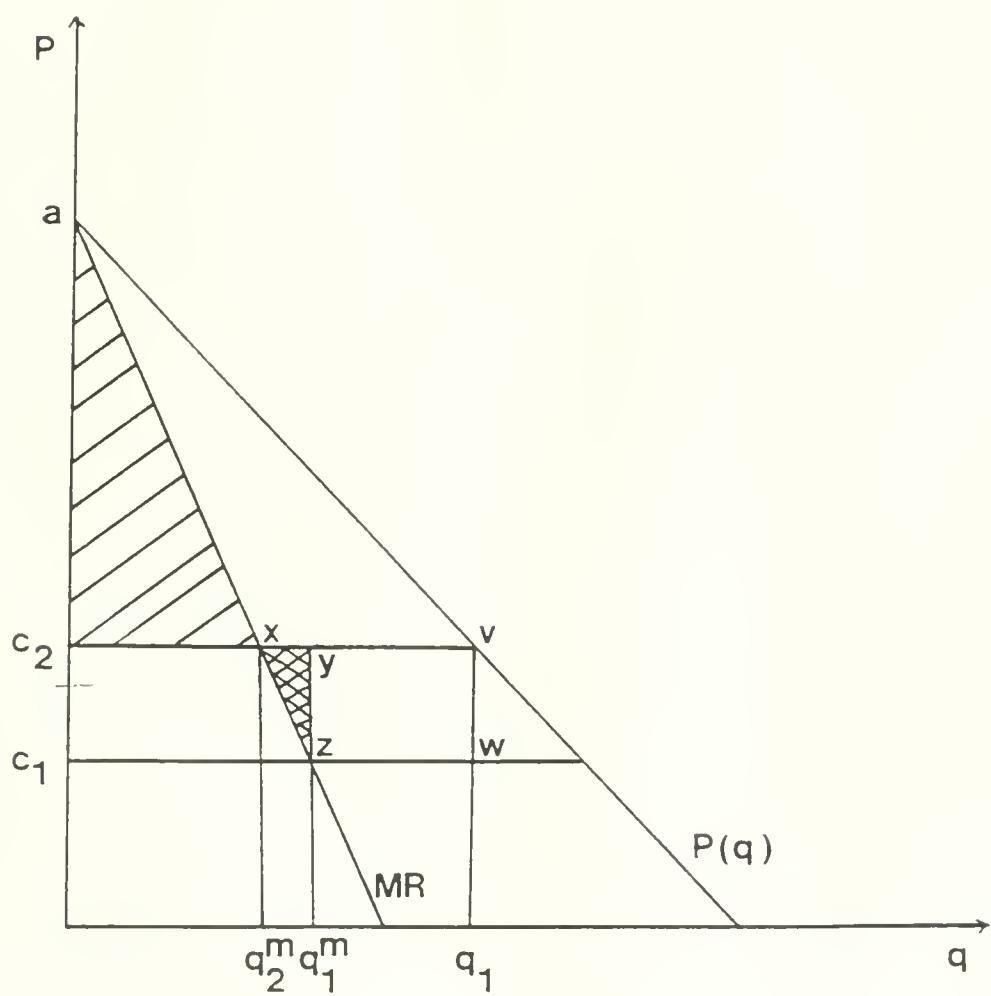


FIGURE 1

change its price, firm 1 can raise it price to  $c_2$  and earn zero (less the fixed cost  $f$ ). On the other hand, if it doesn't change its price it shares the industry loss of  $c_1 c_2 \text{vw}$ . Clearly  $(c_1 c_2 \text{vw})/2$  always exceeds  $(xyz)$ . Thus the duopolist always has a greater incentive to increase its price.

In some sense the result of this section is not surprising since, as Akerlof and Yellen (1985) argue the cost from not changing one's price is of second order in the change in costs only if the profits function is differentiable with respect to price. This is not true for Bertrand duopolies and indeed (2) is of first order in the change in costs while (1) is of second order. However, as soon as we let the duopoly produce differentiated products, the profit functions become differentiable and both losses are of second order. Yet we show in the following section that as the two goods become better and better substitutes the analysis in this section becomes more relevant.

Note that while Bertrand duopolists respond more to changes in costs they respond less to changes in demand with constant marginal costs the duopoly never changes its price when  $a$  changes. Instead by not changing its prices the monopolists loses an amount quadratic in the change in  $a$ .

This analysis has two shortcomings. First, the duopolists lose money in equilibrium. If they do change their prices the new equilibrium has  $P_2 = c_2$ , but they must incur the fixed cost of changing their prices. If they do not change their prices, they sell at a price less than marginal cost.

Second, the analysis does not carry over to the case of a cost decrease. In that case if both firms change their prices the resulting equilibrium has  $P_2 = c_2$ . Thus each firm loses  $f$ . So one firm can do better by not changing its price, selling nothing, and earning zero profits.

Both of these shortcomings are due to the zero-profit nature of Bertrand competition. We show in the following section that if one allows for some degree of product differentiation these problems disappear. Although the incentive for a duopolist to change its price is somewhat dampened with differentiated products since demand is less responsive to price differences, we show that duopolists may nonetheless change their prices more frequently than monopolists.

### III. Differentiated Products and Costs of Changing Prices

We consider an industry in which two goods are produced. The demand for goods 1 and 2 is given by:

$$\begin{aligned} q_t^1 &= a/2 - (b/2+d)P_t^1/S_t + dP_t^2/S_t \\ q_t^2 &= a/2 - (b/2+d)P_t^2/S_t + dP_t^1/S_t \end{aligned} \tag{5}$$

where  $a$ ,  $b$  and  $d$  are positive constants,  $S$  is the general price level and  $t=1$  or 2 denotes the period. As can be seen from equation (5), the two goods are symmetric and  $d$  is a measure of their substitutability. The goods can be produced at constant marginal cost  $S_t c$ . In this section we focus particularly on changes in overall prices  $S$  since this is probably the main reason for price changes in the studies mentioned in the introduction. Note that increases in  $S$  do not just raise costs, as in the previous section, but also increase the quantity demanded at any price. This occurs because any given price now represents a smaller amount of real purchasing power.

Therefore, profits deflated by  $S_t$  from producing good 1,  $\pi_t^1$  are given by:

$$\pi_t^1 = [a/2 - (b/2+d)P_t^1/S_t + dP_t^2/S_t](P_t^1/S_t - c) \tag{6}$$

and similarly for good 2.

If the firms simultaneously choose prices and behave noncooperatively, firm 1 chooses  $P_t^1$  to maximize (6). The first order condition is

$$P_t^1 = dP_t^2/(b+2d) + aS_t/(2b+4d) + cS_t/2. \quad (7)$$

The Nash equilibrium prices in the first period if the firms expect  $S_1$  to be equal to  $S_2$  is then:

$$P_1^1 = P_1^2 = [a+c(b+2d)]S_1/2(b+d).$$

It is useful to rewrite (6) as:

$$\begin{aligned} \pi^1 = & -(b/2+d) [P_t^1 - dP_t^2/(b+2d) - aS_t/(2b+4d) - cS_t/2]^2/S_t^2 \\ & +(b/2+d) [dP_t^2/S_t(b+2d) + a/(2b+4d) - c/2]^2. \end{aligned} \quad (8)$$

This decomposes  $\pi_1$  into a term incorporating the first order condition (7) and a term that is independent of  $P_t^1$ . Now suppose that  $S$  changes unexpectedly from  $S_1$  to  $S_2$ . We then ask how big this change in  $S$  has to be in order to induce the firms to change their prices in the presence of a fixed cost to changing prices,  $f$ .

We first calculate the increase in firm 1's profits from changing its price from  $P_1^1$  to  $P_2^1$  assuming that firm 2 doesn't change its price ( $P_2^2 = P_1^2$ ). We will show shortly that this gives a lower bound on the increase in firm 1's profits from changing its price. The change in firm 1's profit is:

$$\begin{aligned} \Delta\pi_1 = & -(b/2+d)[P_2^1 - dP_2^2/(b+2d) - aS_2/(2b+4d) + cS_2/2]^2/S_2^2 \\ & +(b/2+d)[P_1^1 - dP_2^2/(b+2d) - aS_2/(2b+4d) + cS_2/2]^2/S_2^2. \end{aligned} \quad (9)$$

But notice that  $P_2^1$  will be set equal to the price that maximizes  $\pi^1$  given that firm 2 is setting  $P_1^2$ . Using (7), the first term is equal to zero. Thus

we have

$$\Delta\pi_1 = (b/2+d)[P_1^1 - dP_2^2/(b+2d) - aS_2/(2b+4d)+cS_2/2]^2/S_2^2. \quad (10)$$

Using (3) and rearranging this gives

$$\Delta\pi^1 = (\frac{\Delta S}{S_2})^2 (b/2+d)[a/(b+2d) + c]^2/4 \quad (11)$$

where  $\Delta S$  is  $S_1 - S_2$ .

It is immediate from (10) that this gives a lower bound to the change in firm 1's profits from changing its price. This can be seen by noting that increases (decreases) in firm 2's price tend to increase (10) when  $S_2$  increases (decreases). (To see this notice that  $a/(2b+4d) > c/2$  if the monopoly price exceeds marginal cost. Also,  $P_1^1 = dP_2^2/(b+2d) + aS_2/(2b+4d) - cS_2/2$ . If  $S_2$  increases, the RHS of this expression exceeds  $P_1^1$ . This difference is increased if  $P_2^2$  also increases. Similarly, if  $S_2$  decreases, the RHS is less than  $P_1^1$ . The difference between the LHS and RHS is then increased if  $P_2^2$  is decreased.)

Thus when (11) exceeds  $f$  a duopolist will always change its price.

Compare this with the situation for a monopolist. To bias the argument against our case we suppose that the monopolist can change both of its prices if it incurs the cost  $f$ . Algebra analogous to that above yields the result that the increase in a monopolist's profits from changing its price is

$$(\frac{\Delta S}{S_2})^2 b[a/b+c]^2/4. \quad (12)$$

The difference between (12) and (11), the monopolist's and duopolist's incentives to change price, is proportional to:

$$b(a/b+c)^2 - (b/2+d)(a/(b+2d)+c)^2. \quad (13)$$

The derivative of (13) with respect to  $d$  is

$$[a/(b+2d)]^2 - c^2$$

which is negative for  $d$  bigger than  $(a-bc)/2c$ . As  $d$  increases this derivative converges to the constant  $-c^2$  so that, for  $d$  sufficiently big, (11) exceeds (12) and duopolists change their prices in response to smaller changes in  $S$ . If one considers the example in which  $a$  equals 10,  $c$  equals 5 and  $b$  equals 1, then if  $d$  exceeds 7 duopolists will change their prices whereas the monopolist will not.

We now turn to an interpretation of these results. An increase in  $S$  has two effects. It raises demand and costs at the current price. The simplified model of the previous section provides the intuition for why the duopolists have a greater incentive to change their prices in response to a cost change. With differentiated products, the cost change has an effect proportional to  $b$  on the monopolist's desire to change its price, and an effect proportional to  $(b/2+d)$  on each duopolist. If  $d$  is greater than  $b/2$  the latter effect is larger.

Duopolists are less affected by the change in demand on the other hand. This can be seen by analyzing directly the effect on the incentive to change prices of changes in  $a$ . These have an impact on the desirability of changing prices proportional to  $a/4b$  for the monopolist while the effect on each duopolist is proportional to  $a/8(b+2d)$ . Even when  $d$  is zero, the effect on the duopolists is smaller simply because the firms are smaller. As  $d$  goes

up, the duopolist becomes even less concerned until with  $\alpha=\infty$  demand stops mattering. A higher  $d$  means that the demand curve perceived by the duopolist becomes flatter. This means that any given horizontal translation in demand leads to smaller gains from changing the price. Suppose the demand goes up (as it would when  $S$  rises). Then a firm with a steep demand would raise its price substantially gaining large profits from consumers relatively unwilling to stop purchasing. Instead, firms with very elastic demand curves would raise their prices little and lose substantial customers in the process.

Thus when  $d$  is large the demand effect becomes insignificant and the cost effect becomes paramount. Therefore, for  $d$  large, the duopolists are more willing to change their prices in response to changes in the price level than monopolists.

These results are broadly consistent with the simulations of Akerlof and Yellen (1985) and Blanchard and Kiyotaki (1985). They compute the lost profits from keeping prices unchanged as a fraction of profits in the former case and as a fraction of revenues in the latter. Both these papers show that in response to a small increase in the money supply these fractions are higher the lower is the elasticity of the demand facing firms. This is consistent with our paper insofar as our results also depend on duopolists having flatter perceived demand curves than monopolists. Yet these apparent similarities mask some important differences. First, comparing only the elasticity of demand across firms does not take into account that monopolists are different from individual oligopolists both in that they are larger and are subject to fewer strategic interactions.<sup>2</sup> Second, insofar monopolists

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<sup>2</sup>For instance, Akerlof and Yellen (1985) assume that the fraction of firms who keep their prices constant (i.e. who are near-rational) is independent of the structure of demand.

have higher profits (or revenues) than oligopolists, considering only ratios of the type studied by Akerlof and Yellen (1985) and Blanchard and Klyotaki (1985) tends to make monopolists automatically appear to view fixed prices as less onerous. Finally, their simulations do not place firms in contexts in which general inflation (or, as in the 30's deflation) affects costs together with demand.

#### IV. Search Costs

The results in the previous sections rely on fixed costs of changing prices. In this section we show that similar results can be obtained even in the absence of these costs. In particular, we show that a cost  $s$  of learning the actual value of marginal cost can lead to relative rigidity of monopoly pricing. Duopolists are more likely than monopolists to spend  $s$  and adjust their price accordingly. This result has the interpretation that monopolists are "lazy" when it comes to collecting information. As a result, in an environment in which costs are stochastic and independently distributed over time, monopolists tend to keep their prices constant while duopolists don't.

While this result shows that the principle that monopolists have less responsive prices than duopolists does not hinge on costs of changing prices it is important to remember that the costs considered in this section cannot explain constant prices in the face of publicly known aggregate price movements. These movements would induce price changes by both monopolists and oligopolists as long as these firms recognize that such movements are at least somewhat correlated with their own costs of production.

We consider again an industry that produces two differentiated products whose demands are given by (5). We abstract from inflation and normalize  $S$  to equal one. Costs are stochastic and distributed independently in the

first and second periods. Since this makes the analysis static we can consider just one period, say the second one.

Actual cost equal  $c + \varepsilon$  where  $c$  is a constant while  $\varepsilon$  is a random variable with mean zero. Thus, in the duopoly case firm 1 maximizes:

$$E_1 [a/2 - (b/2+d)P_1 + dP_1](P_1 - c - \varepsilon) \quad (14)$$

where  $E_1$  takes expectations conditional on information available to firm 1.

This leads to the following first order condition:

$$P_1 = E_1 [a/2 + dP_2 + (b/2+d)(c+\varepsilon)]/(b+2d) \quad (15)$$

and similarly for firm 2:

$$P_2 = E_2 [a/2 + cP_1 + (b/2+d)(c+\varepsilon)]/(b+2d). \quad (16)$$

If either firm does not search, one can obtain its (uninformed) price  $P_u$  by the law of iterated expectations:

$$P_u = [a/2 + (b/2+d)c]/(b+d). \quad (17)$$

If both firms charge this price expected profits of each equal  $K$  which is given by:

$$K = (b/2+d)(a/2 - bc/2)^2/(b+d)^2.$$

If firm 2 does not search and firm 1 does, then substituting  $P_u$  from (17) for  $P_2$  in (15) yields the result that firm 1 charges  $P_u + \varepsilon/2$ .

Then, substituting this in (14), firm 1's expected profits equal:

$$K + (b/2 + d)E\varepsilon^2/4. \quad (18)$$

So if one of the firms (say firm 2) does not find out the true value of marginal costs and the variance of  $\varepsilon$  exceeds  $4s/(b/2+d)$ , its rival has an incentive to search. In other words, when the variance of  $\varepsilon$  exceeds  $4s/(b/2+d)$  there is no equilibrium in which neither firm searches.

Suppose firm 1 does search and charge  $P_u + \varepsilon/2$ . Then substituting this value of  $P_1$  in (16) the optimal price for firm 2 is once again  $P_u$ . Firm 2's expected profits are then given by:

$$K = dE\epsilon^2. \quad (19)$$

As an aside notice that firm 2's profits in (19) are lower than when neither firm searches. When one firm searches it can charge a high price when  $\epsilon$  is high and a low price when  $\epsilon$  is low. As a result, the other firm obtains an inordinately large number of customers when costs are high and few customers when costs are low leading to large losses in profits.

We now proceed to show that the profits in (19) are so low that it is not an equilibrium for one firm not to search when the other searches.

Suppose firm 1 searches and charges  $P_u + \epsilon/2$ . Then, substituting this in (16) firm 2 would charge  $P_u + (b+3d)\epsilon/(2b+4d)$  if it were to search as well. This would result in profits of:

$$K + (b+d)^2 E\epsilon^2 / 8(b+2d). \quad (20)$$

So the net benefits from searching are equal to the expression in (20) minus the expression in (19). This equals:

$$[d + (b+d)^2 / 8(b+2d)]E\epsilon^2 = [(b/2+4d)/4 + d^2 / 8(b+2d)]E\epsilon^2$$

which exceeds  $(b/2+d)E\epsilon^2 / 4$ , the incentive to search unilaterally when the other firm does not search.

Having shown that for one firm not to search while the other searches is not an equilibrium<sup>3</sup> we now show that for both firms to search is always an equilibrium whenever one firm would search unilaterally. In other words we show that when the variance of  $\epsilon$  exceeds  $4s(b/2+d)$  neither firm wants to deviate from the equilibrium in which both search.

If both firms search and are aware that they both search then the equilibrium price is  $P_n$ :

$$P_n = [a/2 + (b/2+d)(c+\epsilon)]/(b+d)$$

which leads to profits of:

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<sup>3</sup>Note that we focus only on pure strategy equilibria and neglect the possibility that strategies involve random searching.

$$K + b^2(b/2 + d)E\varepsilon^2/4(b+d)^2. \quad ^4 \quad (21)$$

If firm 2 ceases to search but firm 1 continues to charge  $P_n$  the optimal price for firm 2 becomes  $P_u$  and its expected profits equal:

$$K - d(b/2 + d)E\varepsilon^2/(b+d) \quad (22)$$

Taking the difference between (21) and (22) one obtains the net benefit to searching given that the other firm searches. This is given by:

$$(b/2+d)[b^2/4(b+d)^2 + d/(b+d)] E\varepsilon^2 = (b/2 + d)(b + 2d)^2 E\varepsilon^2/4(b+d)^2$$

which, as long as  $d$  is positive, exceeds  $(b/2+d)E\varepsilon^2/4$  the incentive for the first firm to search unilaterally. Thus if one firm searches, the other always searches as well.

Again to bias our results in favor of finding the oligopolists changing their prices infrequently, we assume that the duopoly only gathers information on marginal cost when each firm (taken individually) would want to do so.

When the two firms are combined in a monopoly, the combined firm maximizes:

$$E(P - c - \varepsilon)(a - bP)$$

so that its optimal price is given by  $[a/2b + c/2 + E\varepsilon/2]$ . Thus if the monopoly does not search, and charges  $[a/2b + c/2]$ , its expected profits equal  $K'$ :

$$K' = b(a/b - c)^2/4.$$

If it does search it obtains expected profits equal to  $K' + bE\varepsilon^2/4$ . Thus it only searches if  $E\varepsilon^2$  exceeds  $4s/b$  where  $s$  are the search costs.

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<sup>4</sup>Note that this is lower than the profits in (18) obtained when only one firm searches. Now, firms that search cannot take advantage of the other firm's unresponsiveness to costs.

Remember that the duopoly searches when  $E\varepsilon^2$  exceeds  $4s/(b/2+d)$ . So, as long as  $d$  exceeds  $b/2$  so that the slope of each duopolist's demand curve is flatter than the monopolist's, the duopoly will always search when the monopolists does but not viceversa.

#### V. Conclusions

We have shown that the cost from not changing one's price is generally lower for monopolists than for members of a tight oligopoly. As a result, in the two period models we present, circumstances which lead a monopolist to change its prices would always encourage duopolists to do so as well while the reverse is not true. In this conclusion we point out a few caveats and possible extensions of the analysis.

First, our analysis has been concerned exclusively with the monopoly-duopoly comparison. Yet, Carlton (1985) as well as Stigler (1947) suggest that price rigidity is monotonic in concentration so that duopolies change their prices less often than three firm oligopolies and so on. The analysis of this paper can probably be extended to cover these cases as well. What was crucial in our analysis is that perceived demand curves become flatter as there are more competitors. This makes price changes more attractive because some of the benefits derive at the expense of competitors. Insofar as oligopolists with many competitors can reasonably be thought to have perceived demand curves that are more elastic (because there are better substitutes produced by competitors for instance), they will change their prices more frequently.

Second, our analysis of the actual frequency of price adjustment applies strictly only in our two period setting. An extension to a more general dynamic setting thus seems desirable. In some sense this extension

should be straightforward; as the incentives for changing prices are bigger for oligopolies, we should observe them changing their prices more often. Unfortunately when considering dynamic games between duopolists one must allow the strategies of the firms to depend on the history of their relationship. This considerably complicates the analysis. In particular, since price changes may precipitate price wars, there may be equilibria in which duopolies are reluctant to change their prices.<sup>5</sup>

Another important area for future research is the interaction between the two types of imperfections we consider; costs of changing prices and costs of finding out information about costs. It would seem that a small amount of costs of changing prices is necessary to explain why firms do not change their prices everytime some public information about the economy is released. What is conceivable is that costs of collecting information exacerbate the reluctance to change prices. Such costs mean that the firm will only occasionally know its "optimal" price. Insofar as customers are mainly upset about "unjustified" price changes, i.e. price changes which are either not based on good information or which are reversed, the presence of large search costs may prolong the duration of fixed prices.

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<sup>5</sup>For some dynamic models that use a framework capable of addressing these difficult questions see Gertner (1985) and Sheshinski and Weiss (1985).

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